$\boxed{7.17}$ Si: $N_a = 2\times10^{17}\,cm^{-3}$

$N_d = 4\times10^{16}\,cm^{-3}$

$T = 300\,K$

$A = 2\times10^{-4}\,cm^2$

$V_R = 2.5\,V$

a) $$V_{bi} = \frac{kT}{e}\ln\left(\frac{N_aN_d}{n_i^2}\right) = 0.0259V\cdot\ln\left(\frac{(2\times10^{17}cm^{-3})(4\times10^{16}cm^{-3})}{(1.5\times10^{10})^2}\right)$$

$$\boxed{= 0.808V}$$

b) $$x_n = \left[\frac{2\epsilon_s(V_{bi}+V_R)}{e}\left(\frac{N_a}{N_d}\right)\frac{1}{N_a+N_d}\right]^{1/2}$$

$$= \left[\frac{2(11.7)(8.85\times10^{-14}F/cm)(0.808V+2.5V)}{(1.6\times10^{-19}C)}\left(\frac{2\times10^{17}cm^{-3}}{4\times10^{16}cm^{-3}}\right)\frac{1}{2\times10^{17}cm^{-3}+4\times10^{16}cm^{-3}}\right]^{1/2}$$

$$= 2.987\times10^{-5}\,cm = \boxed{0.2987\,um}$$

$$x_p = x_n\frac{N_d}{N_a} = (0.2987\,um)\frac{(4\times10^{16}cm^{-3})}{(2\times10^{17}cm^{-3})}\boxed{= 0.05974\,um}$$

$$W = x_n + x_p = \boxed{0.3584\,um}$$

c) $$|E_{max}| = \frac{2(V_{bi}+V_R)}{W} = \frac{2(0.808V+2.5V)}{0.3584\times10^{-4}cm}$$

$$\boxed{= 1.846\times10^{5}\,V/cm}$$

d) $$C' = \left\{\frac{e\epsilon_sN_aN_d}{2(V_{bi}+V_R)(N_a+N_d)}\right\}^{1/2}$$

$$= \left[\frac{(1.6\times10^{-19}C)(11.7)(8.85\times10^{-14}F/cm)(2\times10^{17}cm^{-3})(4\times10^{16}cm^{-3})}{2(0.808V+2.5V)(2\times10^{17}cm^{-3}+4\times10^{16}cm^{-3})}\right]^{1/2}$$

$$C' = 2.889\times10^{-8}\,F/cm^2$$

$$\Rightarrow C = C'\cdot A = \boxed{5.778\times10^{-12}\,F} = 5.78\,pF$$

$\boxed{7.19}$ Si n^+p , $V_R = 5V$

a) $V_{bi} = \frac{kT}{e} \ln\left(\frac{N_a N_d}{n_i^2}\right)$

if $N_a \rightarrow 3N_a$

$V_{bi\,new} = \frac{kT}{e} \ln\left(\frac{3N_a N_d}{n_i^2}\right) = \frac{kT}{e}\ln(3) + V_{bi}$

$V_{bi\,new} = 0.0285\,V + V_{bi}$

$$\boxed{\Delta V_{bi} = 0.0285\,V}$$

b) For one sided n^+p

$C' = \left[\frac{e\epsilon_s N_a}{2(V_{bi}+V_R)}\right]^{1/2}$

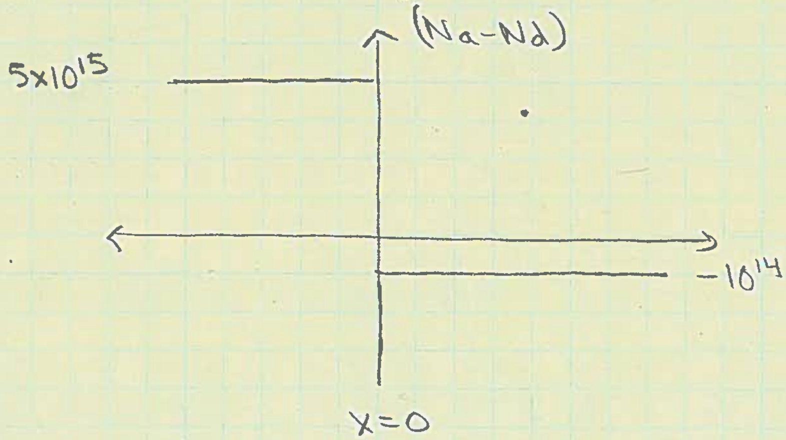
$C'_{new} = \left[\frac{e\epsilon_s 3N_a}{2(V_{bi}+V_R)}\right]^{1/2}$

so $\frac{C'_{new}}{C'} = \left[\frac{e\epsilon_s 3N_a}{2(V_{bi}+V_R)} \cdot \frac{2(V_{bi}+V_R)}{e\epsilon_s N_a}\right]^{1/2} = \boxed{\sqrt{3} = 1.732}$

c) Junction capacitance increases as N_a increases because the space-charge narrows. Since the junction is is kind of like a parallel plate capacitor, we can see that capacitance goes up as the space charge width goes down by

$C = \frac{\epsilon A}{d}$ ← space charge width

7.28 Si pn junction $T = 300K$



* note: this plot is Na-Nd, so the p-side is on the left (as usual)

a) $V_{bi} = \frac{kT}{e} \ln\left(\frac{(5\times10^{15})(1\times10^{14})}{(1.5\times10^{10})^2}\right) = \boxed{0.557\ V}$

b) $x_n = \left[\frac{2\epsilon_s V_{bi}}{e}\left(\frac{N_a}{N_d}\right)\frac{1}{N_a+N_d}\right]^{1/2}$

$x_n = \left[\frac{2(11.7)(8.85\times10^{-14}\ F/cm)}{(1.6\times10^{-19}\ c)}\left(\frac{5\times10^{15}\ cm^{-3}}{1\times10^{14}\ cm^{-3}}\right)\frac{1}{(5\times10^{15}\ cm^{-3}+1\times10^{14}\ cm^{-3})}\right]^{1/2}$

$= 3.56\times10^{-4} = \boxed{3.56\ um}$

so $x_p = x_n \frac{N_d}{N_a} = 3.56\,um\frac{(1\times10^{14})}{(5\times10^{15})} = \boxed{0.071\ um}$

c) For $x_n = 30\ um$

$$V_R = \frac{x_n^2 \cdot e}{2\epsilon_s}\cdot\frac{N_d}{N_a}(N_a+N_d) - V_{bi}$$

$$V_R = \frac{(30\times10^{-4}\,cm)^2(1.6\times10^{-19}\,c)(1\times10^{14}\,cm^{-3})(5\times10^{15}\,cm^{-3}+1\times10^{14}\,cm^{-3})}{2(11.7)(8.85\times10^{-14}\ F/cm)(5\times10^{15}\,cm^{-3})} - 0.557V$$

$$\boxed{V_R = 70.4\ V}$$

$\boxed{7.30}$ p^+n silicon $N_a = 2\times10^{17}\ cm^{-3}$, $N_d = 2\times10^{15}\ cm^{-3}$

$A = 10^{-5}\ cm^2$

a) $$V_{bi} = 0.0259V \ln\left(\frac{2\times10^{17}\cdot 2\times10^{15}}{(1.5\times10^{10})^2}\right) = \boxed{0.731\ V}$$

b) $$C' = \left[\frac{e\epsilon_s N_d}{2(V_{bi}+V_R)}\right]^{1/2} \longrightarrow C = A\cdot C'$$

$$C = (1\times10^{-5}\ cm^{-2})\left[\frac{(1.6\times10^{-19}c)(11.7)(8.85\times10^{-14}\ F/cm)(2\times10^{15}\ cm^{-3})}{2\ (V_{bi}+V_R)}\right]^{1/2}$$

$$C = \frac{1.29\times10^{-13}}{\sqrt{V_{bi}+V_R}}$$

(i)
$$\boxed{\begin{array}{ll} V_R = 1\ V, & C = 9.80\times10^{-14}\ F \\ V_R = 3V, & C = 6.663\times10^{-14}\ F \\ V_R = 5V, & C = 5.376\times10^{-14}\ F \end{array}}$$

c) $$C = \frac{1.29\times10^{-13}}{\sqrt{V_{bi}+V_R}}$$

$$\Longrightarrow \frac{1}{C^2} = \frac{V_{bi}+V_R}{1.664\times10^{-26}}$$

$$= \frac{1}{1.664\times10^{-26}} V_R + \frac{V_{bi}}{1.664\times10^{-26}}$$

so $$\boxed{\frac{1}{C^2} = 6.01\times10^{26}\ V_R + 4.39\times10^{25}}$$

See Matlab Plot

$$C = A\left[\frac{e\epsilon_s N_d}{2(V_{bi}+V_R)}\right]^{1/2} \Longrightarrow \frac{1}{C^2} = \frac{1}{A^2}\,\frac{2(V_{bi}+V_R)}{e\epsilon_s N_d}$$

so $$\frac{1}{C^2} = \underbrace{\frac{2}{A^2 e\epsilon_s N_d}}_{\text{slope} \to N_d} V_R + \underbrace{\frac{2V_{bi}}{A^2 e\epsilon_s N_d}}_{\text{intercept} \to V_{bi}}$$

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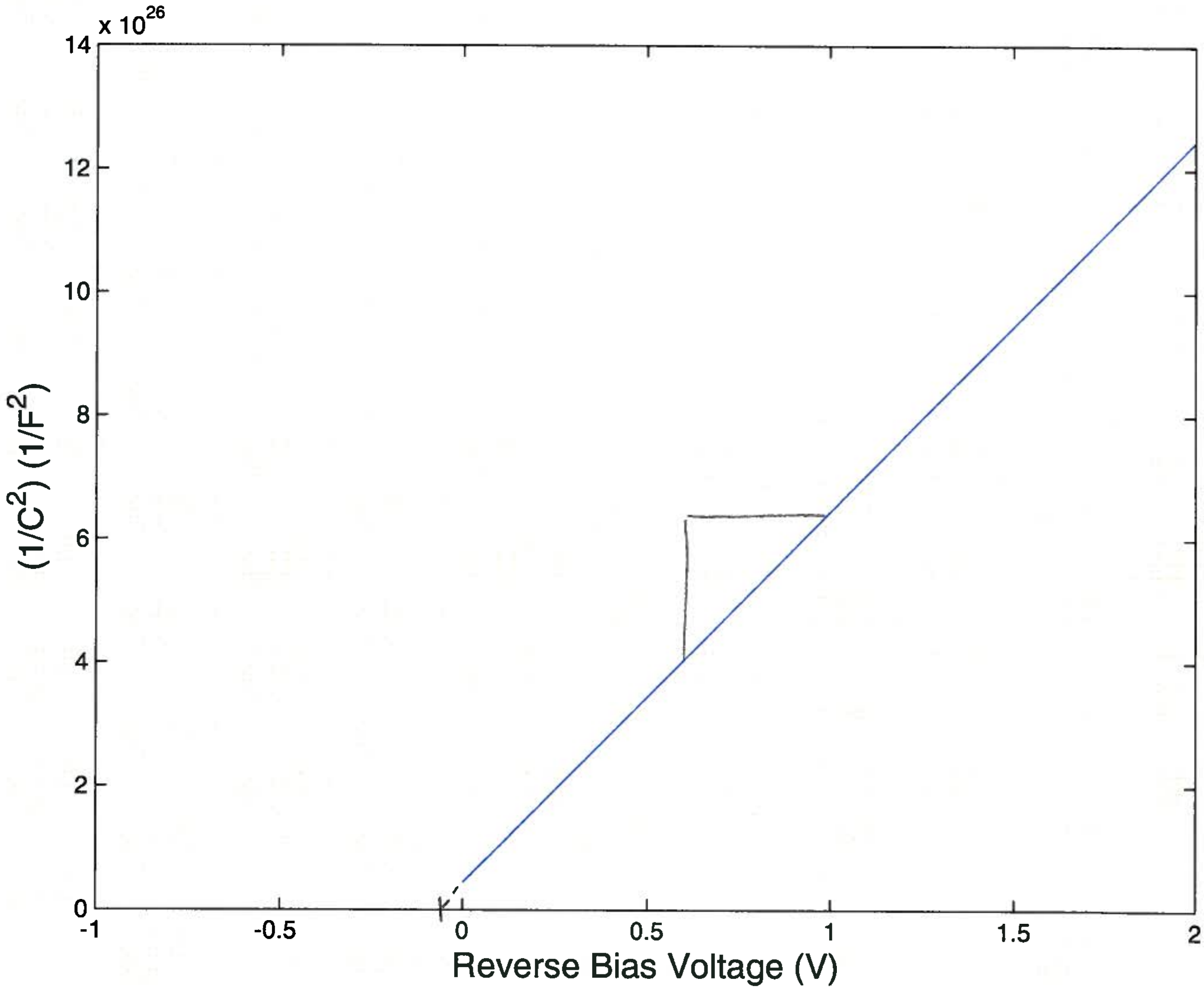
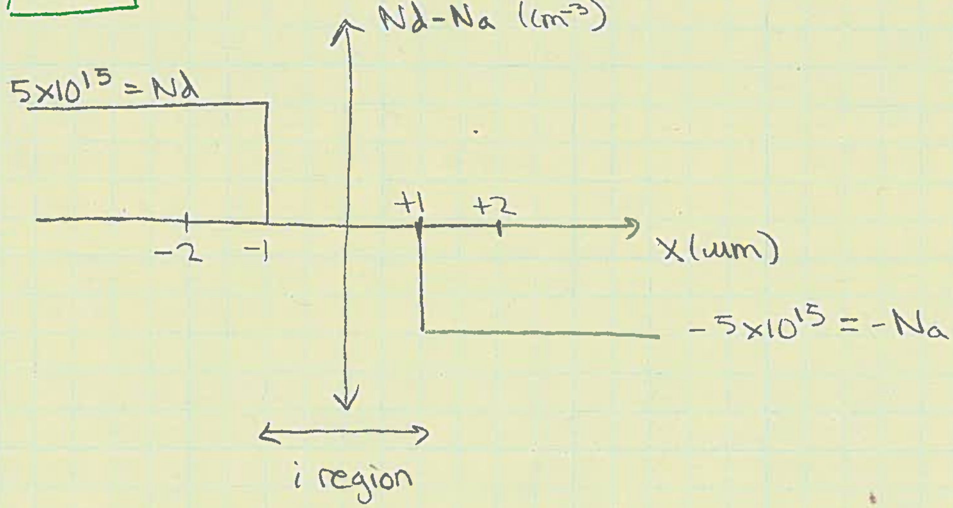
7.30 (c)


x 10^{26}
14
12
10
8
6
4
2
0
-1
-0.5
0
0.5
1
1.5
2
$(1/C^2)$ $(1/F^2)$
Reverse Bias Voltage (V)

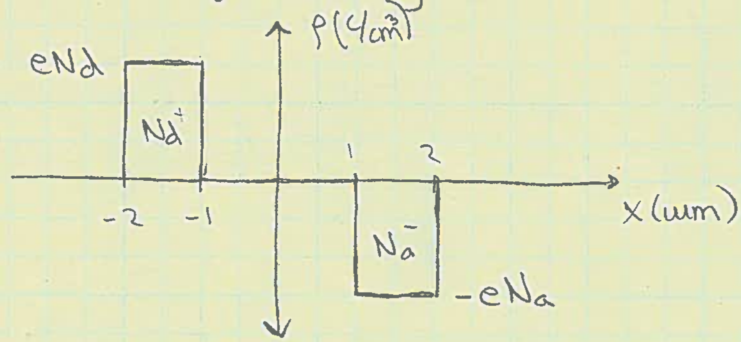
7.34



- Reverse bias and total depletion width is from -2um to 2um

a) Calculate Electric Field Magnitude at $x=0$ using Poisson

1. Draw charge Density



$$\rho(x) = \begin{cases} eN_d & -2 \le x \le -1 \\ 0 & -1 \le x \le 1 \\ -eN_a & 1 \le x \le 2 \end{cases}$$

$$\frac{dE}{dx} = \frac{\rho(x)}{\epsilon_s}$$

$$E(x) = \int \frac{\rho(x)}{\epsilon_s}\,dx$$

call $-2 = -x_n$, $-1 = -x_i$, $1 = x_i$, $2 = x_p$ } x_i, x_n, x_p are positive

<u>in n-region:</u> $E(x) = \int \frac{eN_d}{\epsilon_s}\,dx = \frac{eN_d}{\epsilon_s}x + C_1$

using $E(-x_n) = 0 \Rightarrow 0 = -\frac{eN_d x_n}{\epsilon_s} + C_1 \Rightarrow C_1 = \frac{eN_d x_n}{\epsilon_s}$

so $\boxed{E_n(x) = \frac{eN_d}{\epsilon_s}(x + x_n)}$ ← positive slope

<u>in i-region:</u> $\rho(x) = 0 \Rightarrow \frac{dE_i}{dx} = 0 \Rightarrow E_i(x) = C_2$

since E-Field must be continuous $E_n(-x_i) = E_i(-x_i)$

$-$ so $E_n(-x_i) = \frac{eN_d}{\epsilon_s}(x_n - x_i) = C_2$

so $\boxed{E_i(x) = \frac{eN_d}{\epsilon_s}(x_n - x_i)}$ ← constant

in p-region: $E_p(x) = -\int \frac{eN_a}{\epsilon_s}dx = \frac{-eN_a x}{\epsilon_s} + C_3$

$E_p(x_p) = 0 \Rightarrow -\frac{eN_a x_p}{\epsilon_s} + C_3 = 0$

$\Rightarrow C_3 = \frac{eN_a x_p}{\epsilon_s}$

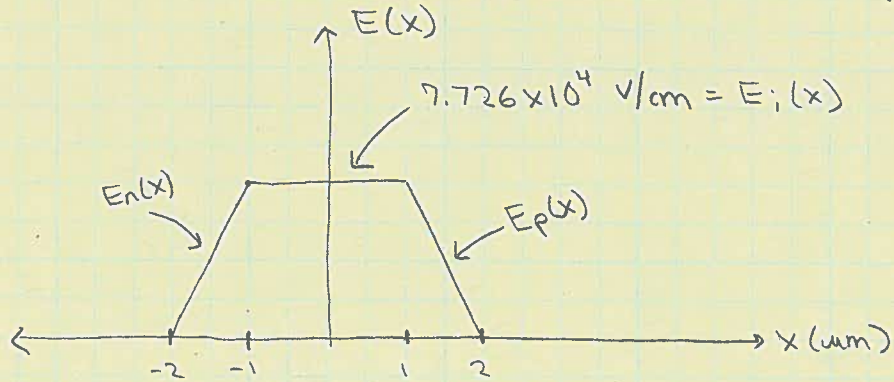
so $\boxed{E_p(x) = \frac{eN_a}{\epsilon_s}(x_p - x)}$ ← negative slope

so $E(0) = E_i(x) = \frac{eN_d}{\epsilon_s}(x_n - x_i)$

$$E(0) = \frac{(1.6\times10^{-19}c)(5\times10^{15}cm^{-3})}{(11.7)(8.85\times10^{-14}F/cm)}(2um - 1um)\left(\frac{1\times10^{-4}cm}{1um}\right)$$

$$\boxed{E(0) = 7.726\times10^{4}\ V/cm}$$

b)



c) The easiest way is to use the area under $E(x)$ curve to get $V_{TOTAL} = V_R + V_{Bi}$ since

$\boxed{\text{approach 1}}$

$$\phi(x) = -\int E(x)\,dx \Longrightarrow V_{TOTAL}$$

then $V_R = V_{TOTAL} - V_{Bi}$

From part (b), the n and p sections give an area of

$$2 \cdot \frac{1}{2} \cdot \underbrace{1\,\text{um}}_{\text{base}} \cdot \left(\frac{1\times10^{-4}\,\text{cm}}{\text{um}}\right) \cdot \underbrace{7.726\times10^{4}\,\text{V/cm}}_{\text{height}}$$

$$= 7.726\text{ V}$$

The intrinsic section gives: $2\,\text{um}\left(\frac{1\times10^{-4}\,\text{cm}}{\text{um}}\right) \cdot 7.726\times10^{4}\,\text{V/cm}$

$$= 15.452\text{ V}$$

so $\boxed{V_{TOTAL} = 23.178\text{ V}}$

and $V_{bi} = \frac{kT}{e}\ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.0259\text{V}\ln\left(\frac{(5\times10^{15})^2}{(1.5\times10^{10})^2}\right) = 0.6587\text{V}$

so $V_R = V_{TOTAL} - V_{Bi} = 23.178\text{V} - 0.6587\text{V}$

$$\boxed{V_R = 22.519\text{ V}}$$

* You can also get this by explicitly integrating the expressions for $E(x)$ you found in part (b) $\boxed{\text{see approach 2}}$

* Note: If you try to use equation (7.34) you will not get the right answer since this only applies for a basic pn-junction

- approach 2

<u>n-region</u>: $\phi_n(x) = -\int \frac{eN_d}{\epsilon_s}(x + x_n)\,dx = \frac{-eN_d}{\epsilon_s}\left(\frac{x^2}{2} + x_n x\right) + C_1'$

now decide on boundary condition: is $\phi(x)$ maximum or minimum at $x = -x_n$?

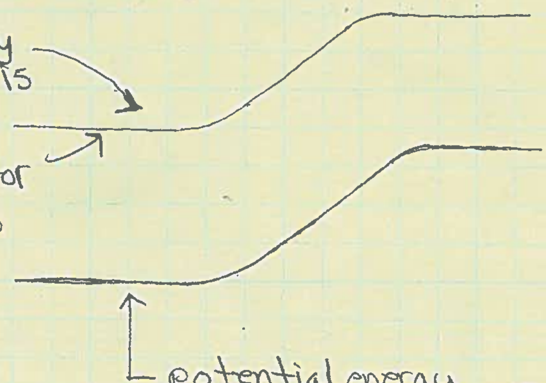
↳ because $E(x)$ is positive and $\phi(x) = -\int E(x)\,dx$

$\Rightarrow$ $\phi(x)$ gets smaller as we go from $-x_n$ to x_p

↳ another way to see it is to look at the energy band diagram

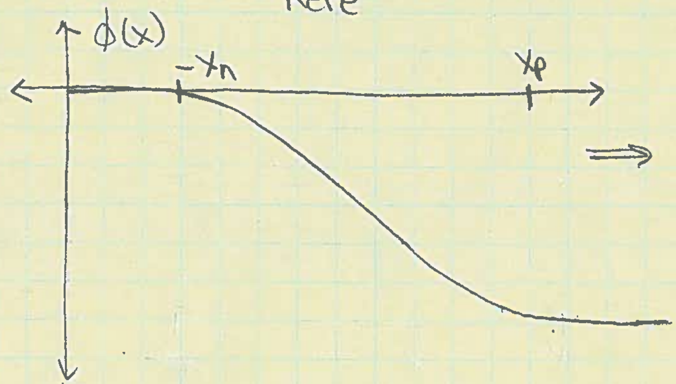
potential energy for electrons is lowest here

$\Rightarrow$ potential for electrons is highest here



potential energy for holes is highest here $\Rightarrow$ potential for holes is also highest here

$\Rightarrow$



$\Rightarrow$ $\phi(-x_n) = 0$

$\phi(x_p) = -V_{TOTAL}$

* let the potential at $x_n = 0$, so the potential at x_p is negative ($-V_{TOTAL}$)

$-V_{TOTAL} = -(V_R + V_{bi})$

so to get C_1': $\phi_n(-x_n) = 0$

$\Rightarrow$ $\frac{-eN_d}{\epsilon_s}\left(\frac{x_n^2}{2} - x_n^2\right) + C_1' = 0$

$-\frac{eN_d}{\epsilon_s}\frac{x_n^2}{2} = C_1'$ so $\phi_n(x) = -\frac{eN_d}{2\epsilon_s}\left(x^2 + 2x_n x + x_n^2\right)$

$$\boxed{\phi_n(x) = \frac{-eN_d}{2\epsilon_s}(x + x_n)^2}$$

i-region: $E_i(x) = \frac{eN_d}{\epsilon_s}(x_n - x_i)$

$$\phi_i(x) = -\int \frac{eN_d}{\epsilon_s}(x_n - x_i)\,dx = -\frac{eN_d}{\epsilon_s}(x_n - x_i)x + C_2'$$

now $\phi_i(-x_i) = \phi_n(-x_i)$

$$\Rightarrow \quad \frac{eN_d}{\epsilon_s}(x_n - x_i)x_i + C_2' = -\frac{eN_d}{2\epsilon_s}(x_n - x_i)^2$$

$$\text{so} \quad C_2' = -\frac{eN_d}{2\epsilon_s}(x_n - x_i)^2 - \frac{eN_d}{2\epsilon_s}\,2(x_n - x_i)x_i$$

$$= \frac{-eN_d}{2\epsilon_s}\left[(x_n - x_i)^2 + 2(x_n - x_i)x_i\right]$$

$$C_2' = \frac{-eN_d}{2\epsilon_s}\left[(x_n - x_i)(x_n + x_i)\right]$$

$$\text{so} \quad \phi_i(x) = \frac{-eN_d}{\epsilon_s}\left[(x_n - x_i)x + \frac{(x_n - x_i)(x_n + x_i)}{2}\right]$$

$$\boxed{\phi_i(x) = \frac{-eN_d(x_n - x_i)}{2\epsilon_s}\left[2x + (x_n + x_i)\right]}$$

p-region: $\phi_p(x) = -\int \frac{eN_a}{\epsilon_s}(x_p - x)\,dx = -\frac{eN_a}{\epsilon_s}\left(x_p \cdot x - \frac{x^2}{2}\right) + C_3'$

boundary condition $\phi_i(x_i) = \phi_p(x_i)$

$$\Rightarrow \quad \frac{-eN_d(x_n - x_i)}{2\epsilon_s}\left[3x_i + x_n\right] = \frac{-eN_a}{\epsilon_s}\left(x_p x_i - \frac{x_i^2}{2}\right) + C_3'$$

$$\text{so} \quad C_3' = \frac{-eN_d}{2\epsilon_s}(x_n - x_i)\left[3x_i + x_n\right] + \frac{eN_a}{\epsilon_s}\left(x_p x_i - \frac{x_i^2}{2}\right)$$

so $\phi_p(x) = -\frac{eN_a}{\epsilon_s}\left(x_p \cdot x - \frac{x^2}{2}\right) + \frac{eN_a}{\epsilon_s}\left(x_p x_i - \frac{x_i^2}{2}\right) - \frac{eN_d}{2\epsilon_s}(x_n - x_i)\left[3x_i + x_n\right]$

$$\boxed{\phi_p(x) = -\frac{eN_a}{2\epsilon_s}\left[2x_p x - x^2 - 2x_p x_i + x_i^2\right] - \frac{eN_d}{2\epsilon_s}(x_n - x_i)\left[3x_i + x_n\right]}$$

now $\phi_p(x_p) = -V_{TOTAL}$, and since $N_a = N_d$

so $-V_{TOTAL} = \frac{-(1.6\times10^{-19}\,c)(5\times10^{15}\,cm^{-3})}{2(11.7)(8.85\times10^{-14}\,F/cm)}\Big[(2\,um)^2 - 2(2\,um)(1\,um) + (1\,um)^2$

$+ (2\,um - 1\,um)(3\,um + 2\,um)\Big]\left(\frac{1\times10^{-4}\,cm}{um}\right)^2$

$-V_{TOTAL} = -23.178\,V$

so $V_{TOTAL} = 23.178\,V$

$\Longrightarrow V_R = 23.178\,V - \underbrace{0.6578\,V}_{V_{bi}\text{ from above}} \boxed{= 22.52\,V}$

$\boxed{8.2}$ $N_d = 2\times10^{15}\ cm^{-3}$ $N_a = 8\times10^{15}\ cm^{-3}$

$n_p(-x_p) = n_{p_0}\exp\left(\frac{eV_a}{kT}\right)$ $p_n(x_n) = p_{n0}\exp\left(\frac{eV_a}{kT}\right)$

on p-side $p_{p_0} \simeq N_a \Longrightarrow n_i^2 = N_a \cdot n_{p_0}$

$\Longrightarrow n_{p_0} = \frac{n_i^2}{N_a}$

on n-side $p_{no} = \frac{n_i^2}{N_d}$

so $n_p = \frac{n_i^2}{N_a}\exp\left(\frac{eV_a}{kT}\right)$ $p_n = \frac{n_i^2}{N_d}\exp\left(\frac{eV_a}{kT}\right)$

$n_p = \frac{(1.5\times10^{10})^2}{(8\times10^{15})}\exp\left(\frac{V_a}{0.0259}\right) = 28125\exp\left(\frac{V_a}{0.0259}\right)$

$p_n = \frac{(1.5\times10^{10})^2}{2\times10^{15}}\exp\left(\frac{V_a}{0.0259}\right) = 112500\exp\left(\frac{V_a}{0.0259}\right)$

a) $V_a = 0.45V \longrightarrow \boxed{\begin{array}{l} n_p = 9.88\times10^{11}\ cm^{-3} \\ p_n = 3.95\times10^{12}\ cm^{-3}\end{array}}$

b) $V_a = 0.55V \longrightarrow \boxed{\begin{array}{l} n_p = 1.88\times10^{14}\ cm^{-3} \\ p_n = 4.69\times10^{13}\ cm^{-3}\end{array}}$

c) $V_a = -0.55V \longrightarrow \boxed{\begin{array}{l} n_p \simeq 0 \\ p_n \simeq 0\end{array}}$

$\boxed{8.5}$ GaAs pn junction

$N_a = 5\times10^{16}\,cm^{-3}$ $N_d = 10^{16}\,cm^{-3}$

$A = 10^{-3}\,cm^2$ $V_a = 1.10\,V$

a) minority electron diffusion current at $x=-x_p$

$$J_n(-x_p) = \frac{eD_n n_{p0}}{L_n}\left[\exp\left(\frac{eV_a}{kT}\right)-1\right]$$

$$n_{p_0} = \frac{n_i^2}{N_a} = \frac{(1.8\times10^6\,cm^{-3})^2}{5\times10^{16}\,cm^{-3}} = 6.48\times10^{-5}$$

$D_n = 220\,cm^2/s$ (From table 5.2)

$L_n = \sqrt{D_n \tau_{n0}}$

we are not given τ_{n0}, so assume it is 10^{-7} s From EX 8.2

$$\text{so } J_n(-x_p) = \frac{(1.6\times10^{-19}c)(220\,cm^2/s)(6.48\times10^{-5}\,cm^{-3})}{\sqrt{(220\,cm^2/s)(1\times10^{-7}\,s)}}\left[\exp\left(\frac{1.1}{0.0259}\right)-1\right]$$

$$= 1.355\ A/cm^2$$

$$I_n = A\cdot J_n(-x_p) = \boxed{1.35\,mA}$$

b) $$J_p(x_n) = \frac{eD_p p_{n0}}{L_p}\left[\exp\left(\frac{eV_a}{kT}\right)-1\right]$$

$$p_{n0} = \frac{n_i^2}{N_d} = \frac{(1.8\times10^6\,cm^{-3})^2}{1\times10^{16}\,cm^{-3}} = 3.24\times10^{-4}\,cm^{-3}$$

$D_p = 10.4\,cm^2/s$ From table 5.2, $L_p = \sqrt{D_p\tau_{p0}}$

assume $\tau_{p0} = 5\times10^{-8}$ s From EX 8.2

$$J_p(x_n) = \frac{(1.6\times10^{-19}c)(10.4\,cm^2/s)(3.24\times10^{-4}\,cm^{-3})}{\sqrt{(10.4\,cm^2/s)(5\times10^{-8}\,s)}}\left[\exp\left(\frac{1.1}{0.0259}\right)-1\right]$$

$$= 2.083\ A/cm^2$$

$$\Longrightarrow \quad I_p = A \cdot J_p(x_n) = \boxed{2.083 \text{ mA}}$$

c) $$I_{TOT} = I_n + I_p = 1.35 \text{ mA} + 2.08 \text{ mA} = \boxed{3.43 \text{ mA}}$$

8.7

$$J_s = en_i^2\left[\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{no}}} + \frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{p0}}}\right]$$

$$= \left(1.6\times10^{-19}\right)\left(2.4\times10^{13}\right)^2$$

$$\times\left[\frac{1}{4\times10^{15}}\sqrt{\frac{90}{2\times10^{-6}}} + \frac{1}{2\times10^{17}}\sqrt{\frac{48}{2\times10^{-6}}}\right]$$

$$J_s = 1.568\times10^{-4}\ \text{A/cm}^2$$

(a) $I = AJ_s \exp\left(\frac{V_a}{V_t}\right)$

$$= \left(10^{-4}\right)\left(1.568\times10^{-4}\right)\exp\left(\frac{0.25}{0.0259}\right)$$

$$= 2.44\times10^{-4}\ \text{A}$$

or $I = 0.244\ \text{mA}$

(b) $I = -I_s = -AJ_s = -\left(10^{-4}\right)\left(1.568\times10^{-4}\right)$

$$= -1.568\times10^{-8}\ \text{A}$$

8.15

(a) p-side;

$$E_{Fi} - E_F = kT\ln\left(\frac{N_a}{n_i}\right)$$

$$= (0.0259)\ln\left(\frac{5\times10^{15}}{1.5\times10^{10}}\right)$$

or

$$E_{Fi} - E_F = 0.329\ \text{eV}$$

Also on the n-side;

$$E_F - E_{Fi} = kT\ln\left(\frac{N_d}{n_i}\right)$$

$$= (0.0259)\ln\left(\frac{10^{17}}{1.5\times10^{10}}\right)$$

or

$$E_F - E_{Fi} = 0.407\ \text{eV}$$

(b) We can find

$$D_n = (1250)(0.0259) = 32.4\ \text{cm}^2/\text{s}$$

$$D_p = (320)(0.0259) = 8.29\ \text{cm}^2/\text{s}$$

Now

$$J_S = en_i^2\left[\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{nO}}} + \frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{pO}}}\right]$$

$$= \left(1.6\times10^{-19}\right)\left(1.5\times10^{10}\right)^2$$

$$\times\left[\frac{1}{5\times10^{15}}\sqrt{\frac{32.4}{10^{-6}}}+\frac{1}{10^{17}}\sqrt{\frac{8.29}{10^{-7}}}\right]$$

or

$$J_S = 4.426\times10^{-11}\ \text{A/cm}^2$$

Then

$$I_S = AJ_S = \left(10^{-4}\right)\left(4.426\times10^{-11}\right)$$

or

$$I_S = 4.426\times10^{-15}\ \text{A}$$

We find

$$I = I_S \exp\left(\frac{V_D}{V_t}\right)$$

$$= \left(4.426\times10^{-15}\right)\exp\left(\frac{0.5}{0.0259}\right)$$

or

$$I = 1.07\times10^{-6}\ \text{A} = 1.07\ \mu\text{A}$$

(c) The hole current is

$$I_p = en_i^2 A\cdot\frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{po}}}\exp\left(\frac{V_D}{V_t}\right)$$

$$= \left(1.6\times10^{-19}\right)\left(1.5\times10^{10}\right)^2\left(10^{-4}\right)\left(\frac{1}{10^{17}}\right)$$

$$\times\sqrt{\frac{8.29}{10^{-7}}}\exp\left(\frac{V_D}{V_t}\right)$$

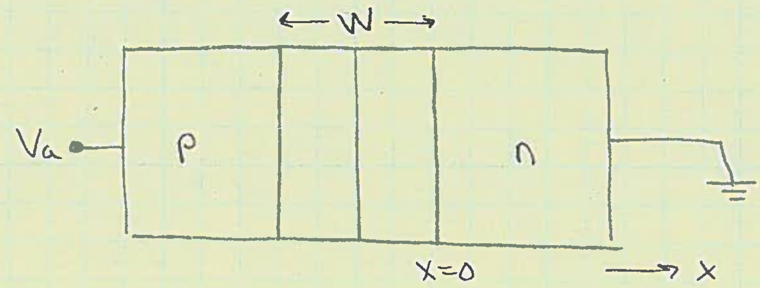
or

$$I_p = 3.278\times10^{-16}\exp\left(\frac{V_D}{V_t}\right)\quad\text{(A)}$$

Then

$$\frac{I_p}{I} = \frac{J_p}{J_S} = \frac{3.278\times10^{-16}}{4.426\times10^{-15}} = 0.0741$$

8.17



T = 300 K

$V_a = 0.61\,V$

$N_d = 10^{16}\ cm^{-3}$ $\quad N_a = 5\times10^{16}\ cm^{-3}$

$\tau_{n0} = 0.05\,\mu s$ $\quad \tau_{p0} = 0.01\,\mu s$

$D_n = 23\ cm^2/s$ $\quad D_p = 8\ cm^2/s$

a) Find excess hole conc as a function of x on the n-side

$$\delta p_n = p_{n0}\left[\exp\left(\frac{eV_a}{kT}\right)-1\right]\exp\left(\frac{x_n - x}{L_p}\right)$$

but since we defined x=0 at the typical x_n point

$$\delta p_n = p_{n0}\left[\exp\left(\frac{eV_a}{kT}\right)-1\right]\exp\left(\frac{-x}{L_p}\right)$$

$$p_{n0} = \frac{n_i^2}{N_d} = \frac{(1.5\times10^{10})^2}{1\times10^{16}} = 22500\ cm^{-3}$$

$$L_p = \sqrt{D_p\tau_{p0}} = \sqrt{(8\ cm^2/s)(0.01\times10^{-6}\ s)} = 2.828\times10^{-4}\ cm$$

so $\delta p_n(x) = (22500\,cm^{-3})\left[\exp\left(\frac{0.61}{0.0259}\right)-1\right]\exp\left(\frac{-x}{2.828\times10^{-4}\,cm}\right)$

$$\boxed{\delta p_n(x) = 3.808\times10^{14}\exp\left(\frac{-x}{2.828\,(\mu m)}\right)\ [cm^{-3}]}$$

b) at $x = 3\times10^{-4}$ cm

$$\delta p_n(3\times10^{-4}\,cm) = 3.808\times10^{14}\exp\left(\frac{-3}{2.828}\right) = 1.318\times10^{14}\,cm^{-3}$$

so $$J_p(3\mu m) = -eD_p \left.\frac{d(\delta p_n(x))}{dx}\right|_{x=3\mu m}$$

$$\frac{d\,\delta p_n(x)}{dx} = -3.808\times10^{14}\exp\left(\frac{-x}{2.828\times10^{-4}\,cm}\right)\cdot\frac{1}{2.828\times10^{-4}\,cm}$$

$$\left.\frac{d\,\delta p_n(x)}{dx}\right|_{x=3\times10^{-4}cm} = -4.66\times10^{17}\,cm^{-4}$$

so $$J_p(3\mu m) = (1.6\times10^{-19}c)(8\,cm^2/s)(4.66\times10^{17}cm^{-4})$$

$$\boxed{J_p(3\mu m) = 0.5965\ A/cm^2}$$

c) Find $J_n(3\mu m)$??

$$J_{no} = \frac{eD_n n_{po}}{L_n}\left[\exp\left(\frac{eV_a}{kT}\right)-1\right]$$

$$n_{po} = \frac{n_i^2}{N_a} = 4.5\times10^3\,cm^{-3}$$

$$L_n = \sqrt{D_n \tau_{no}} = 10.72\,\mu m$$

so $$J_{no} = \frac{(1.6\times10^{-19}c)(23\,cm^2/s)(4.5\times10^3 cm^{-3})}{10.72\times10^{-4}\,cm}\left[\exp\left(\frac{0.61}{0.0259}\right)-1\right]$$

$$= 0.2615\ A/cm^2$$

also $$J_{po} = \frac{(1.6\times10^{-19}c)(8\,cm^2/s)(22500\,cm^{-3})}{2.828\times10^{-4}\,cm}\left[\exp\left(\frac{0.61}{0.0259}\right)-1\right]$$

$$= 1.724\ A/cm^2$$

so $J_{TOT} = J_{n_0} + J_{p_0} = 0.2615\ A/cm^2 + 1.724\ A/cm^2$

$$\boxed{J_{TOT} = 1.985\ A/cm^2}$$

* J_{TOT} is the same everywhere

so $J_n(3\mu m) + J_p(3\mu m) = J_{TOT}$

$\Longrightarrow J_n(3\mu m) = J_{TOT} - J_p(3\mu m)$

$= 1.985 - 0.5965 = \boxed{1.389\ A/cm^2}$